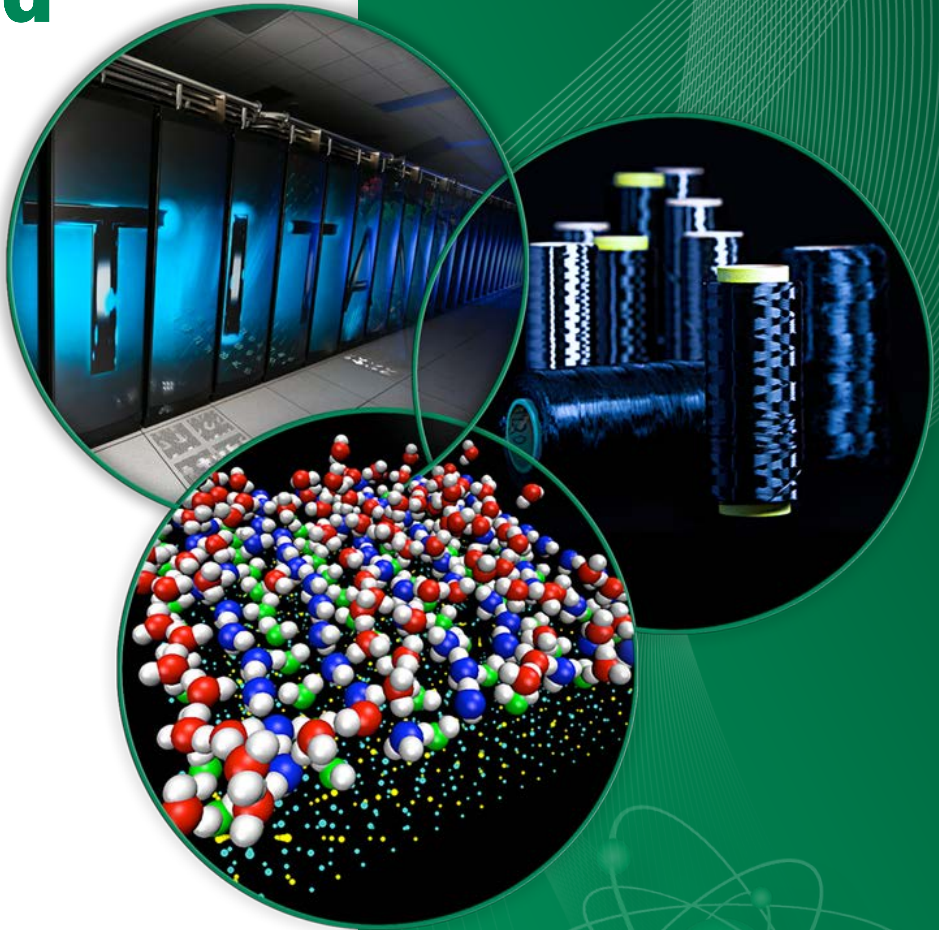
Project ID: LM073

Residual Stress of Bimetallic Joints and Characterization



2013 DOE Vehicle Technologies Annual Merit Review and Peer Evaluation Meeting

May 15, 2013

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Sponsored by

U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Vehicle Technologies Program

Overview

Timeline

- Start: April 28, 2011
- End: April 28, 2014
- 69% complete

Budget

- Total Project funding
  - DOE - $1.385M
  - Vehma-$0.515M
- Funding received:
  - FY12 $350k
  - FY13 $82k approved

Barriers*

- Joining characterization → Diffraction methods applied to access joint integrity

Partner

- Vehma International

* Vehicle Technologies Program, Multi-Year Program Plan 2011-2015, Dec. 2010, pp. 2.5-3.

Relevance: Objective

- To investigate, develop, characterize bimetallic joint integrity after heat treatment.

Relevance to barriers

- *Joining*: Development of non-destructive techniques- Residual stress characterization of HT joints using diffraction to access joint integrity

Relevance to Vehicle Technologies Goals

- Light-Duty Vehicles: By 2015, develop technologies and a set of options to enable up to 50% reduction in light-duty petroleum-based consumption*
- Lightweighting: By 2015,
  - have an industry lead performer design, build and validate a prototype vehicle that is 50 percent lighter weight compared to a 2002 vehicle.*
  - and validate (to within 10 percent uncertainty) the cost-effective reduction of the weight of passenger vehicle body and chassis systems by 50 percent with recyclability comparable to 2002 vehicles.*

◎ Successful characterization of bi-metallic joints will enable a 20% weight reduction relative to baseline steel assembly

* Vehicle Technologies Program, Multi-Year Program Plan 2011-2015, Dec 2010, pp. 1.0-2, 2.5-2.

Overall Technical Approach:

- Manufacture bimetallic samples (joint-only)
- Heat treat bimetallic samples
- Characterization of castings and joints: microstructure, mechanical testing and residual stress profile (neutrons: unique) to access joint integrity

Approach/strategy: Integration within Vehicle Technologies program

- Utilizes characterization tools acquired and formerly maintained by the High Temperature Materials Laboratory (HTML) Program

Current milestones

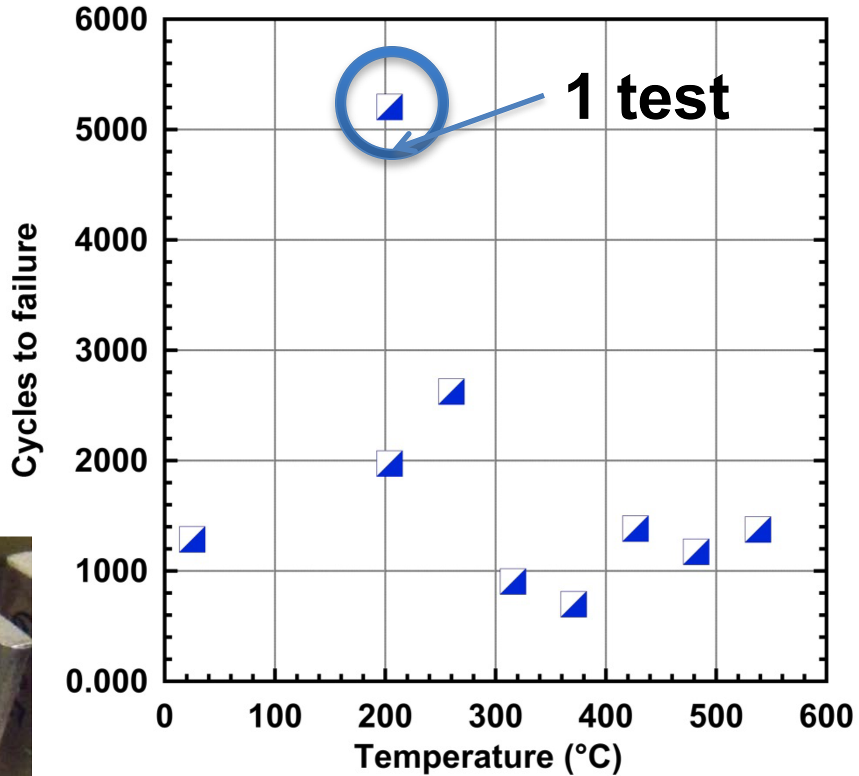
- Complete residual stress measurements on heat treated joint-only samples.

Technical Accomplishment: Experimental joints were fabricated for this study

- **A356 aluminum is cast around a steel tube with welded end cap**
- **First experimental joints:**
  - As-cast (no solutionizing, etc.)
  - T5

Tech.Acc.: At the full capacity of the torsion machine, 2.26 kN-m, the joint remained intact

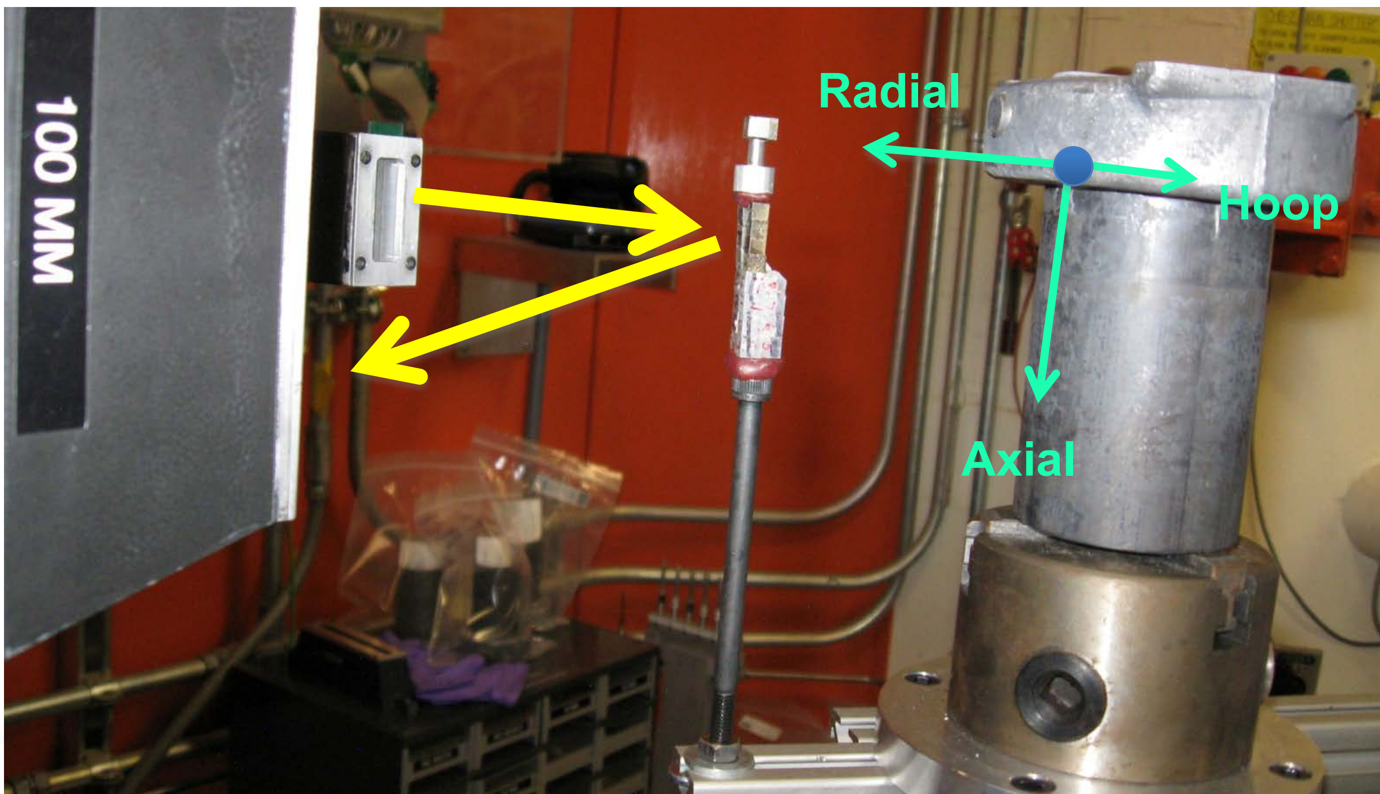
- Next, cyclic fatigue was carried out at 0.5 Hz with amplitude from 2.26 kN-m as function of solutionizing temp.
- Evident that the joint remained completely intact.
- Cast aluminum failed above the joint.

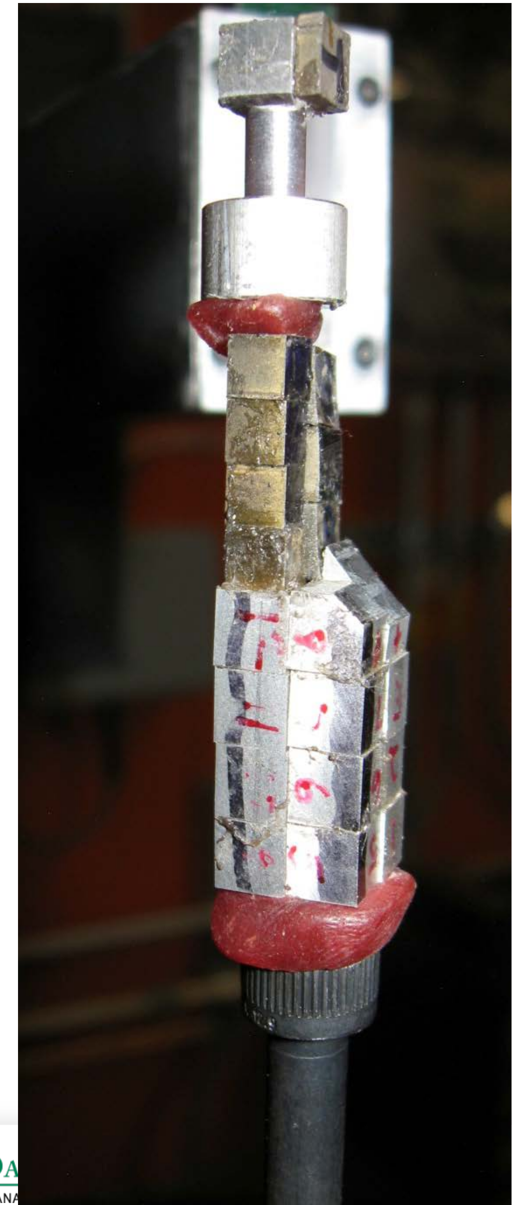


- Cycles to achieve this damage state were < 5000 when the test was terminated.

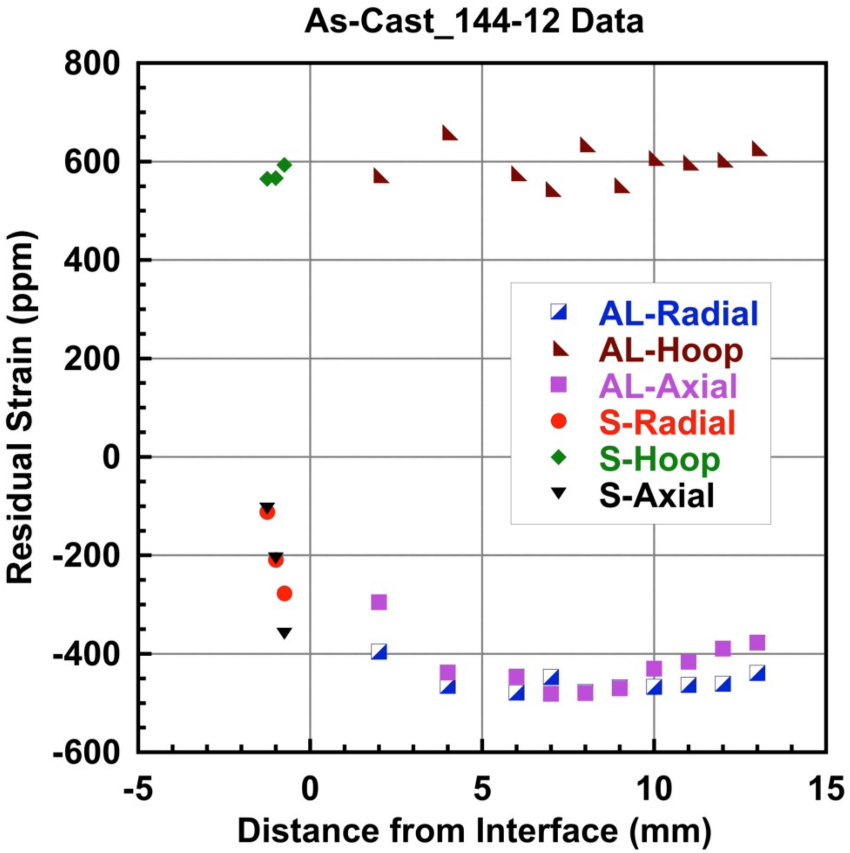
Tech.Acc.: Neutron strain measurements

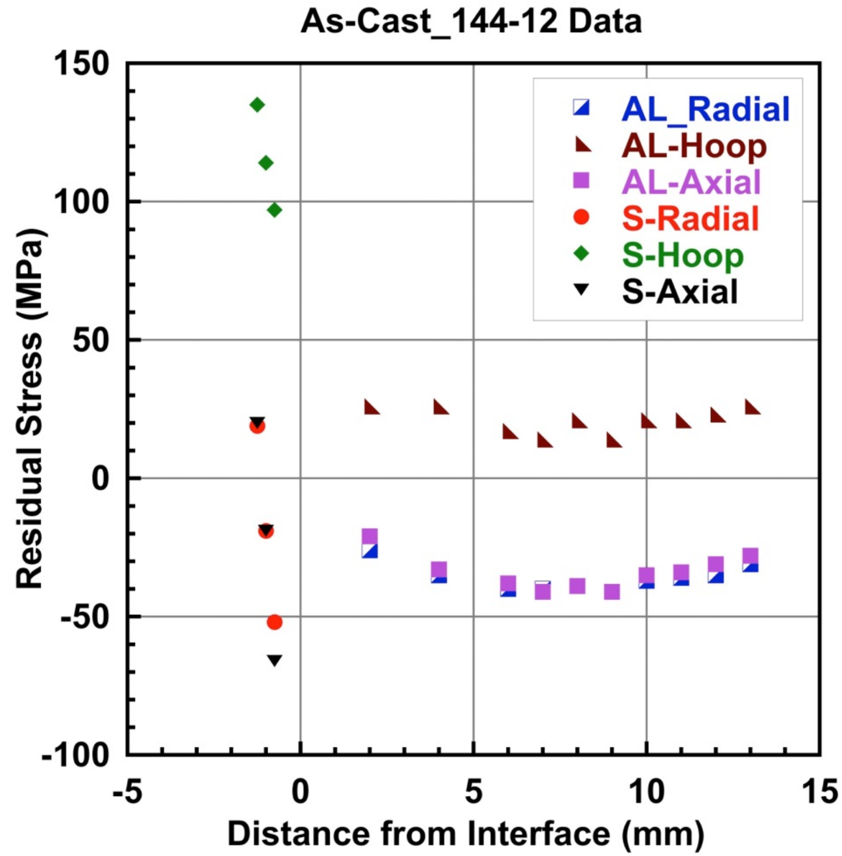
- Cast sample sectioned to improve neutron signal in axial direction
- Stain free reference cubes EDM cut
    - Al-5x5x5mm^3; tube steel 5x6x6; end cap 4x4x4
- References always measured with each sample and in each orientation
- Yellow arrows show neutron beam path





Tech.Acc.: As-Cast: Tensile hoop strains in steel observed, but less tensile than bare tube

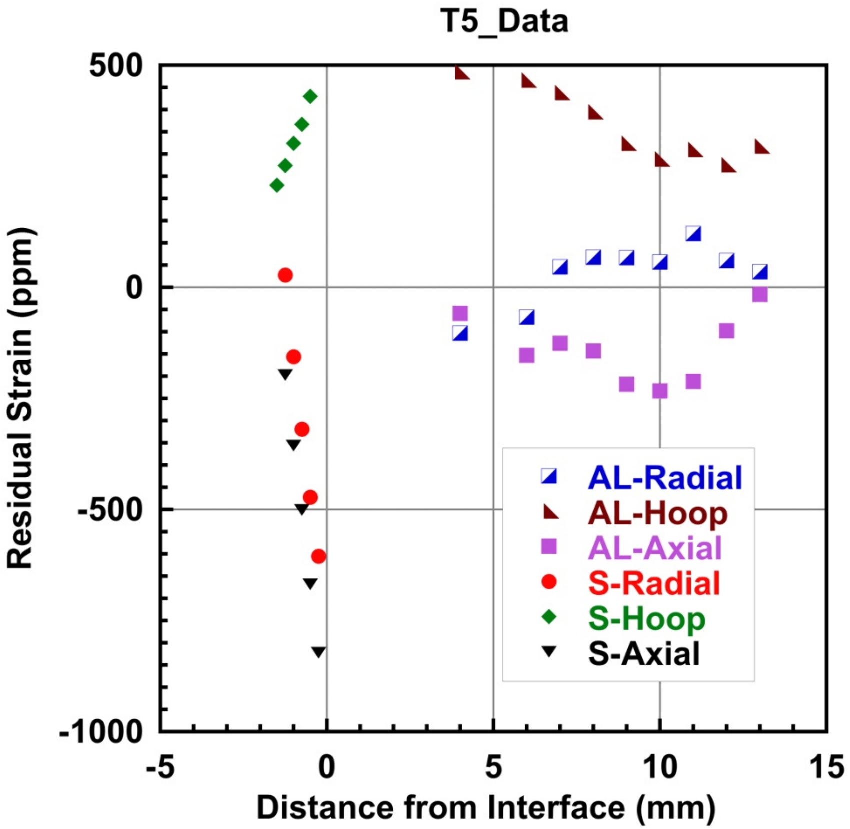


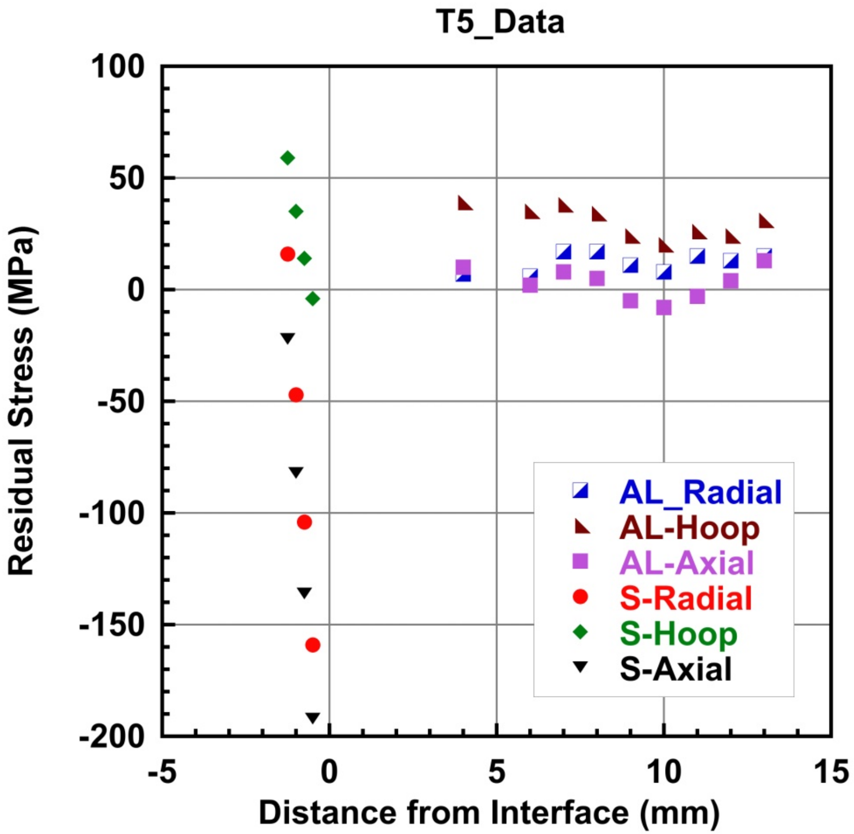


- Analytical solutions* based on an elastic response to thermal expansion mismatch predict compressive hoop strains in steel
- Hoop tension found in steel, partly due to pre-joined condition and partly due to the deformation from molten aluminum injection

*A.C. Ugural & S.K. Fenster, Advanced Strength and Applied Elasticity, 2003; E. Volterra & J.H. Gaines, Advanced Strength of Materials, 1971.

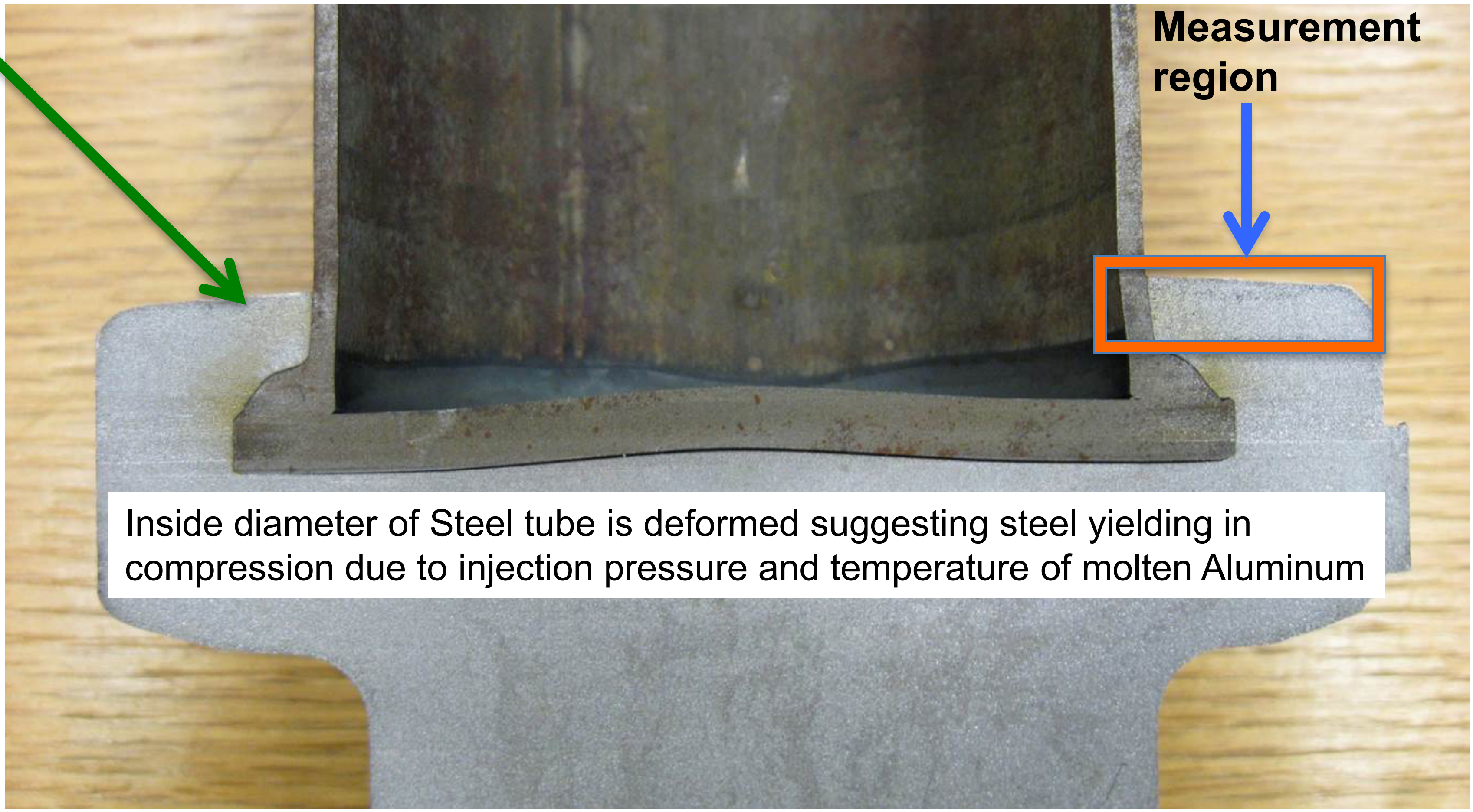
Tech.Acc.: T5: Tensile hoop strains in steel reduced/more compressive





EDM cut reveals tube with welded end cap and joint cross-section

- Molten Aluminum temperature (600-650°C) will drastically lower the yield strength of the steel*
- Injection pressure of aluminum sufficient to deform steel



(*NCMS Report, December 1997, Materials Properties Task Team, Oak Ridge, TN.)

Collaborations and coordinations with other institutions: Partner

- VEHMA INTERNATIONAL (Industry):
  - Vehma's role is to collaborate and guide the work along the most useful path to achieve desired heat treatments and joint integrity
  - Supplies samples
  - Telecons
  - Share experimental results on samples
  - Exchange of technical information to assist with each others analyses
  - Face to face meetings at least 1X/year

Future Work

- Continue model development
- Continue residual stress determinations

Summary

- **Relevance:** Joints will enable weight reduction in automotive assemblies which helps to meet *Lightweighting & VT goals*
- **Approach/Strategy:**
  - Manufacture joints
  - Heat treat joints
  - Characterization of castings and joints: microstructure, mechanical testing and residual stress (neutrons: unique) to access joint integrity
- **Technical Accomplishments:**
  - Go/No Go decision gate metrics met (not shown as CRADA protected)
  - Joints remained completely intact after torsion testing
  - Residual stresses measured in joints
- **Collaborations and Coordination with Other Institutions:** Telecons regularly to discuss latest results
- **Proposed Future Work:** Continue model development and joint characterizations

Technical Backup slides

Gauge volumes defined by intersection of projection of incident and receiving slits

- $\lambda \approx 1.73$ Å
- $2x2x4\ mm^3$ for (311) Al @ 90°2θ
- $0.7x0.7x4\ mm^3$ for (211) steel @ 95.5°2θ
- Volumes balance desired spatial resolution with reasonable count times

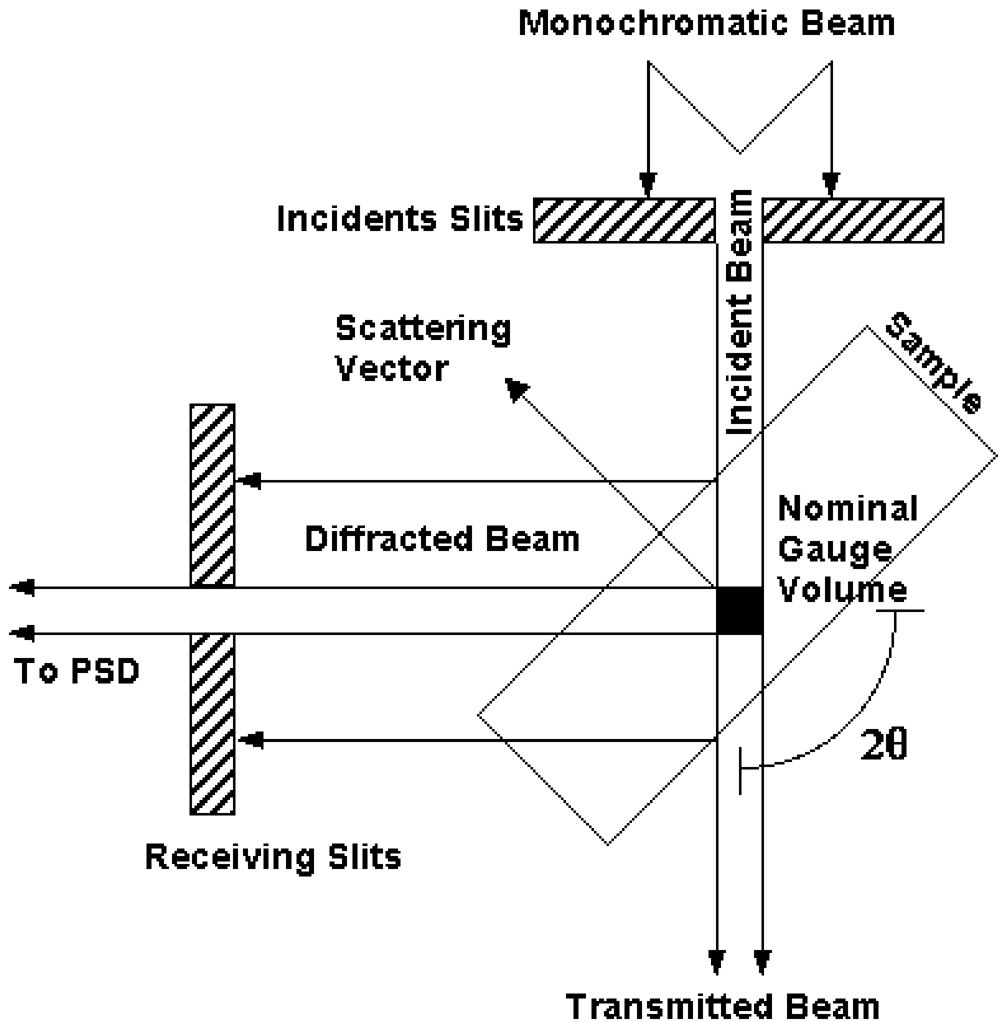


Fig. after Webster et al. Proceedings of the NATO Advanced Research Workshop, 517 1992.

Strains measured and mapped along directions relative to sample shape in 3 orthogonal measurement directions

- Strain: $\varepsilon = (d-d_0)/d_0$
  - d_0 = stress-free interplanar spacing
- Cylinder: Radial, hoop/circumferential, axial
- Shear strains not measured
- Insert ε_{11}, ε_{22}, ε_{33} to solve for σ_{11}, σ_{22}, σ_{33}:

$$\sigma_{ij} = \frac{E}{1+\nu}\left(\varepsilon_{ij} + \frac{\nu}{1-2\nu}\varepsilon_{ii}\delta_{ij}\right)$$